COMPACT PIEZOELECTRIC ULTRASONIC MOTORS

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While electromagnetic motors still dominate the industry, a drastic improvement cannot be expected. Regarding conventional electromagnetic motors, tiny motors smaller than 1cm are rather difficult to produce with sufficient energy efficiency. Therefore, a new class of motors using high power ultrasonic energy --ultrasonic motor-- is gaining wide spread attention. Ultrasonic motors made with piezoceramics whose efficiency is insensitive to size are superior in the mini-motor area.

This paper reviews recent developments of miniature ultrasonic motors using piezoelectric resonant vibrations, which will be a promising candidate for miniature robotics for space applications and medical micro-surgery applications. Following the historical background, ultrasonic motors using the standing and traveling waves are introduced. Driving principles and motor characteristics are explained in comparison with the conventional electromagnetic motors. Finally, the application to a space vehicle is presented.

The ultrasonic motor is characterized by "low speed and high torque," which is contrasted with "high speed and low torque" of the electromagnetic motors. Two categories are being investigated for ultrasonic motors: a standing-wave type and a propagating-wave type. The standing-wave type is sometimes referred to as a vibratory-coupler type or a "woodpecker" type, where a vibratory piece is connected to a piezoelectric driver and the tip portion generates flat-elliptical movement. Attached to a rotor or a slider, the vibratory piece provides intermittent rotational torque or thrust. The standing-wave type has, in general, high efficiency, but lack of control in both clockwise and counterclockwise directions is a problem. By comparison, the propagating-wave type (a surface-wave or "surfing" type) combines two standing waves with a 90 degree phase difference both in time and in space, and is controllable in both rotational directions. By means of the traveling elastic wave induced by the thin piezoelectric ring, a ring-type slider in contact with the "rippled" surface of the elastic body bonded onto the piezoelectric is driven in both directions by exchanging the sine and cosine voltage inputs. Another advantage is its thin design, which makes it suitable for installation in cameras as an automatic focusing device.

We have been developing miniature ultrasonic motors in the size range of 3 - 10 mmf, with using a simple structure and a minimum number of components. A compact rotory motor as tiny as 3 mm in diameter has been fabricated. The stator consists of a piezoelectric ring and two concave/convex metal endcaps with "windmill" shaped slots bonded together, so as to generate a coupled vibration of up-down and tortional type.

When diven at 160 kHz, the maximum revolution 600 rpm and the maximum torque 1 mN.m were obtained for a 3 mm dia motor. An application to a miniature vehicle is cenceptually presented.

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SPONSOR

The Office of Naval Research, USA

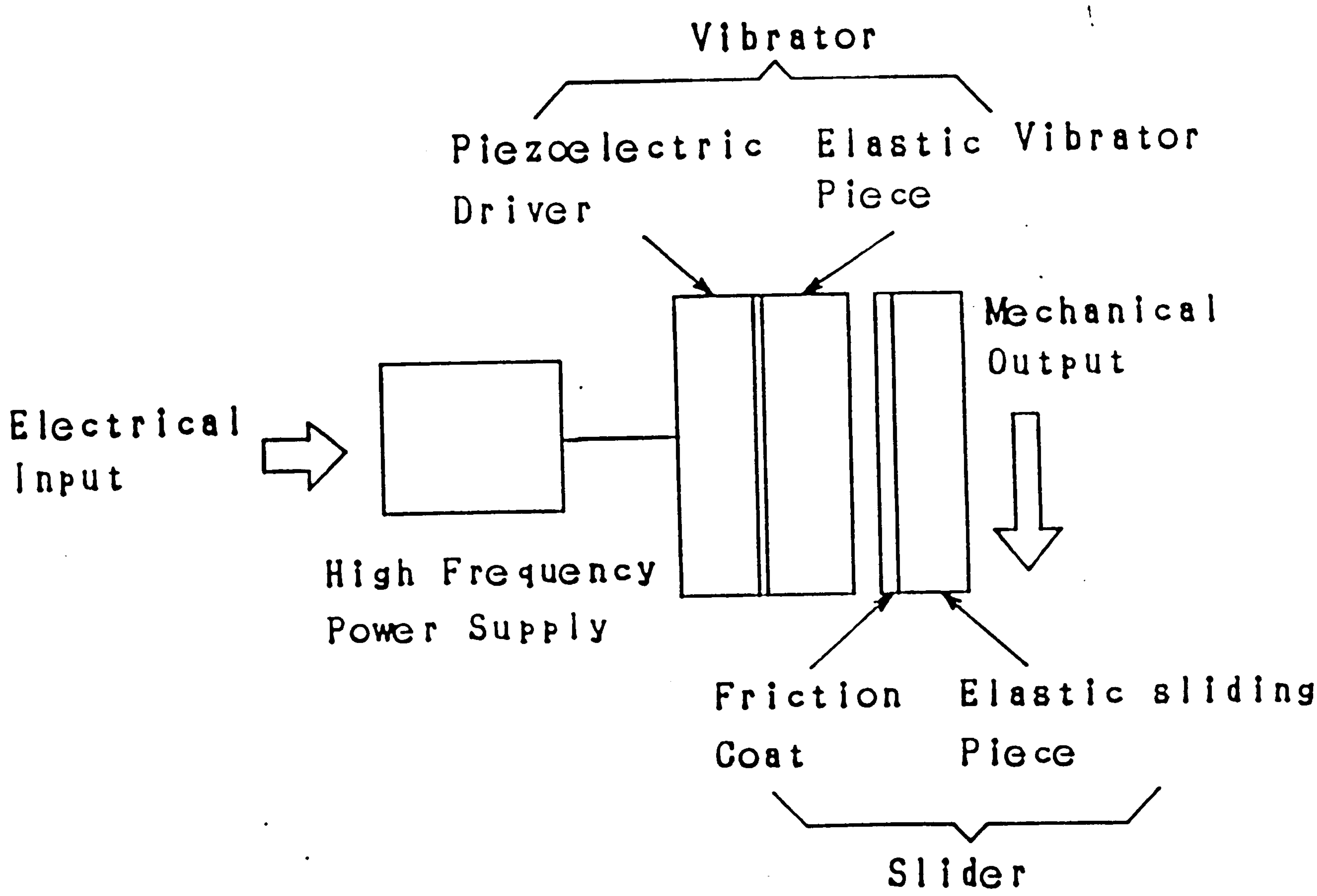
CONTENTS

10 MERITS & DEMERITS OF USM

1. Low speed & high torque - Direct drive
2. Quick response, wide velocity range, hard brake & no backlash
   - Excellent controllability
   - Fine positioning resolution
3. High power/weight ratio & high efficiency
4. Quiet drive
5. Compact size & light weight
6. Simple structure & easy production process
7. Negligible effect from an external magnetic field or radioactive field & no generation of them

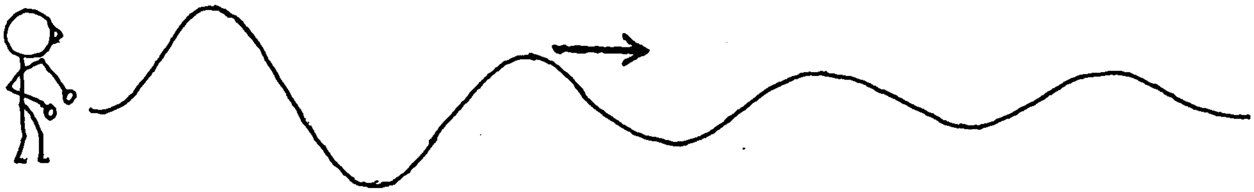
8. Necessity of a high frequency power supply
9. Less durability due to frictional drive
10. Drooping torque-speed characterictics

BASIC CONSTRUCTION



WAVES

"Surfing"



Traveling

"Woodpecker"

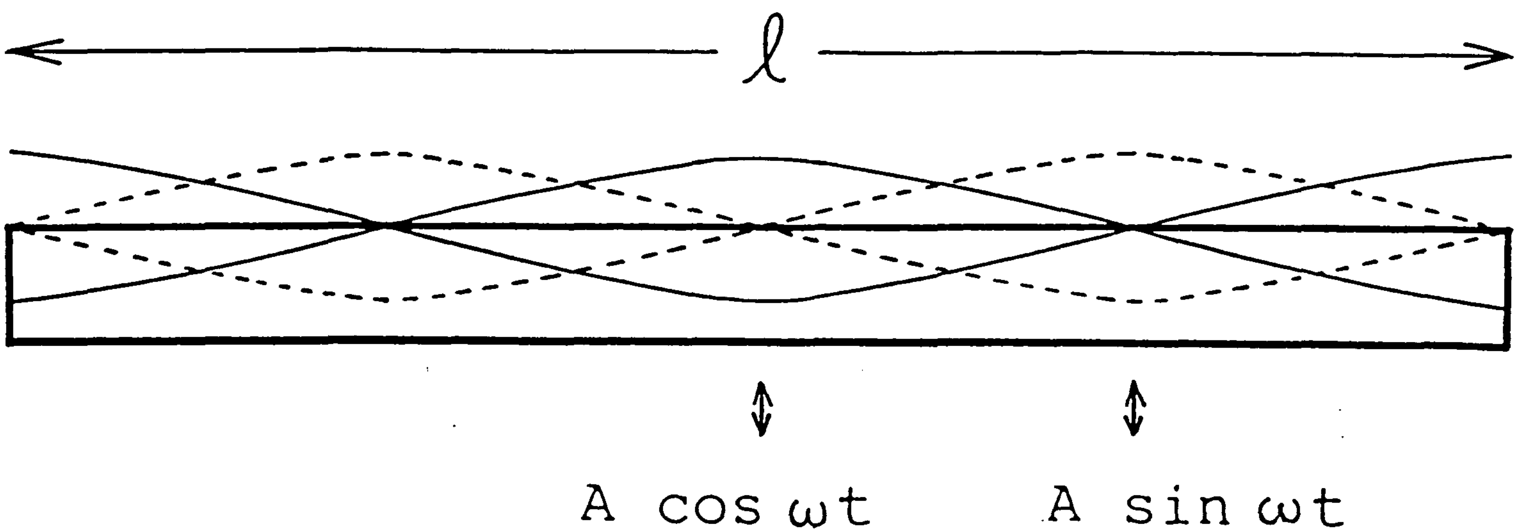
Standing

STANDING WAVE vs. PROPAGATING WAVE

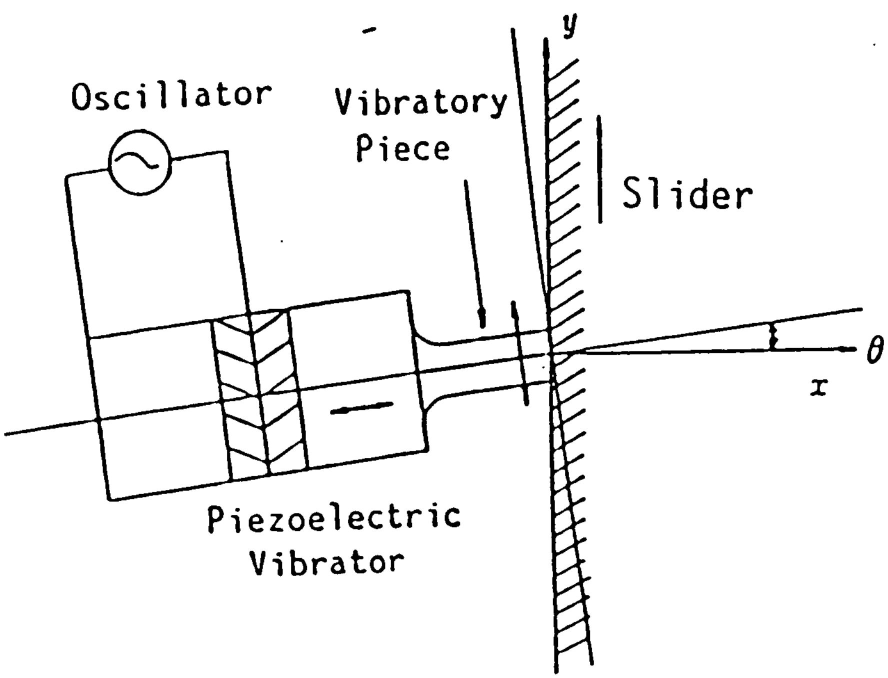
$$u(\mathbf{x},t) = A \cos \mathbf{kx} \cos wt \qquad (1)$$

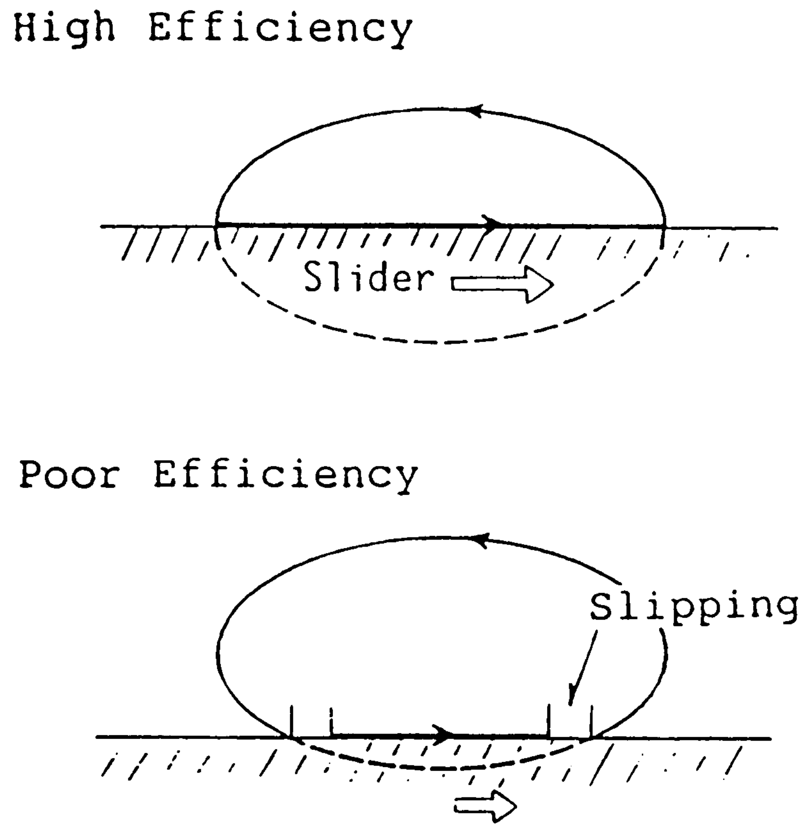
$$\begin{aligned} u(\mathbf{x},t) &= A \cos(\mathbf{kx} - wt) \\ &= A \cos \mathbf{kx} \cos wt \\ &\quad + A \cos(\mathbf{kx} - \pi/2) \cos(wt - \pi/2) \end{aligned} \qquad (2)$$

A propagating wave can be generated by superimposing two standing waves whose phase differs by 90° each other in time and in space.

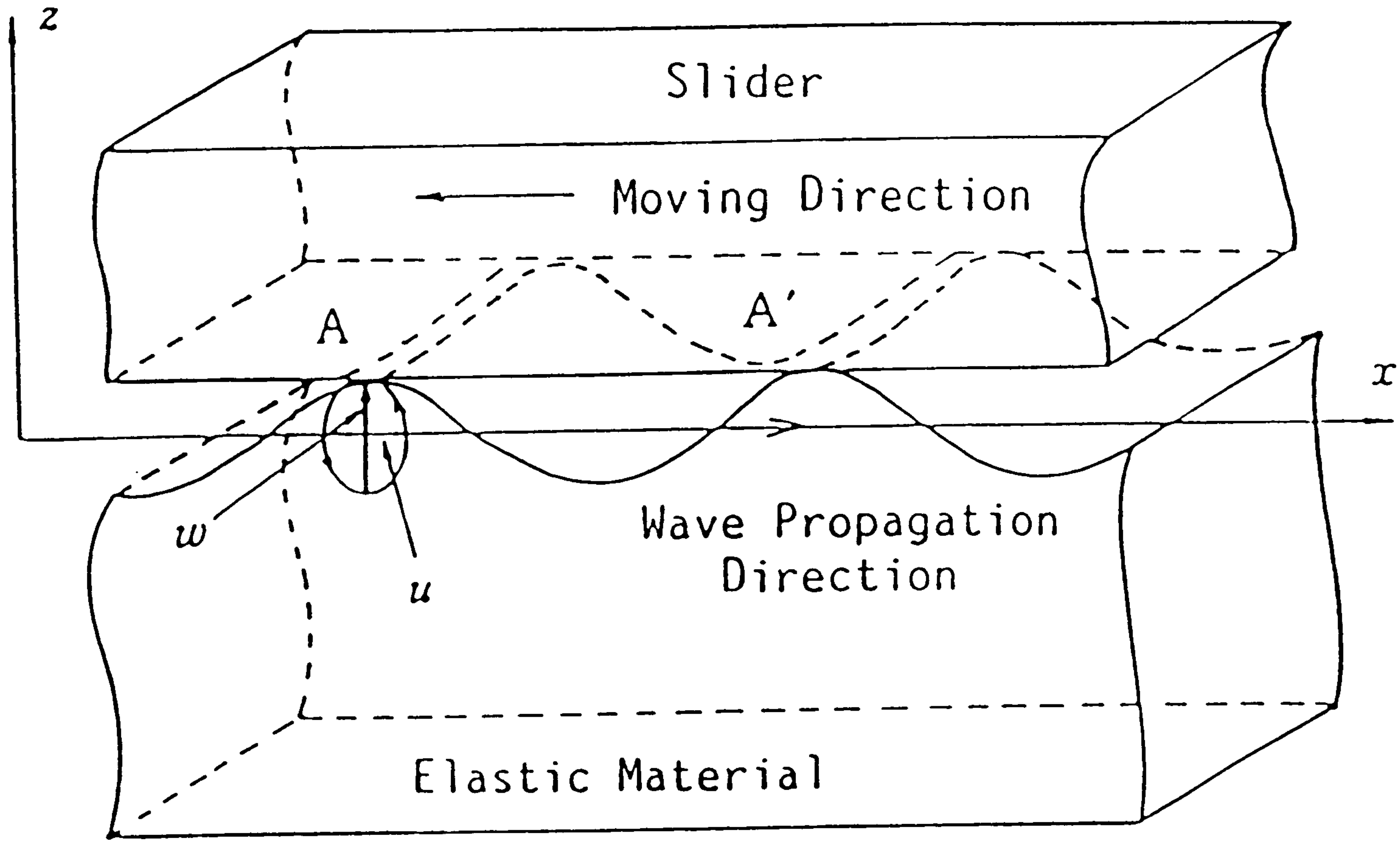


PRINCIPLE OF STANDING WAVE TYPE MOTOR

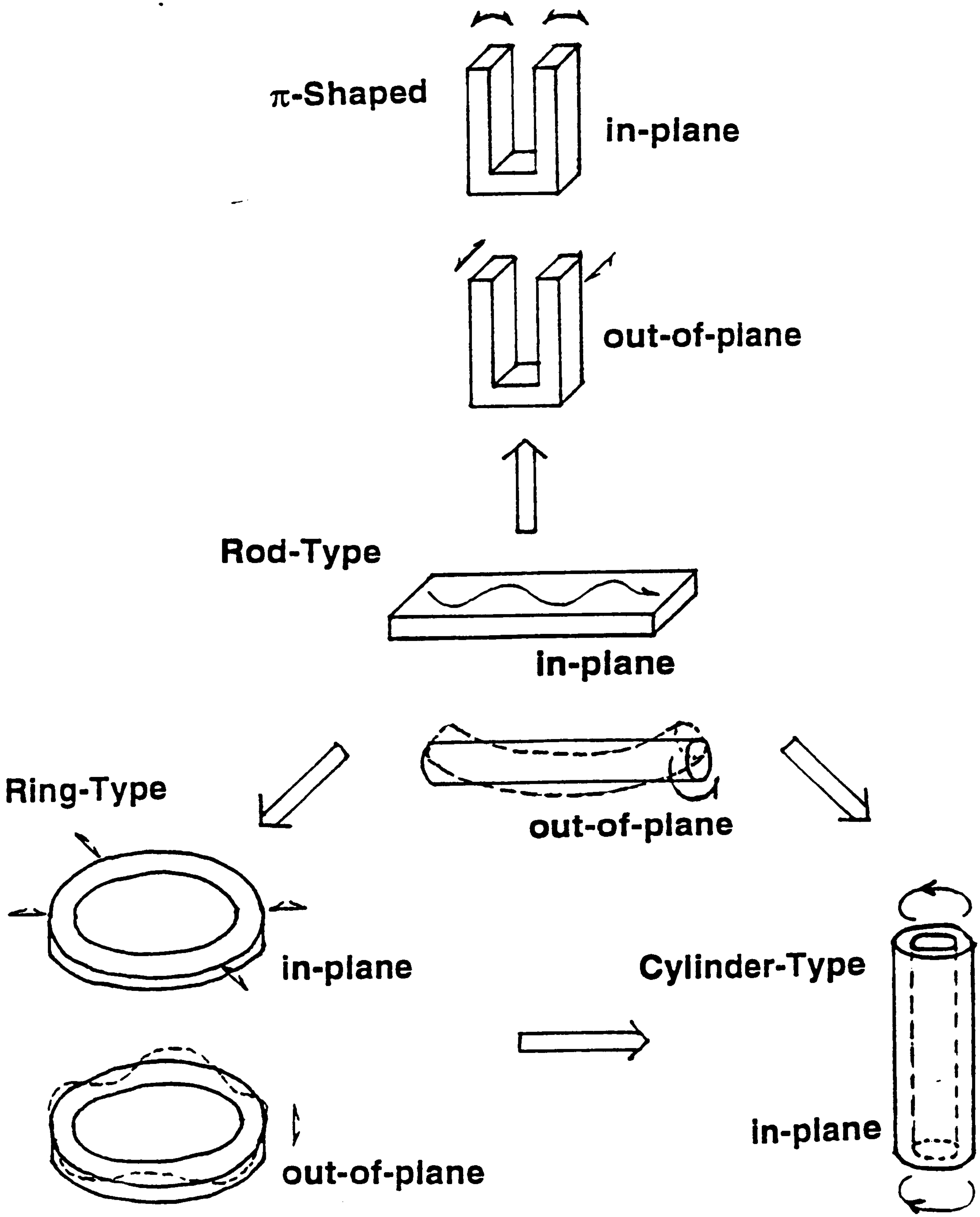


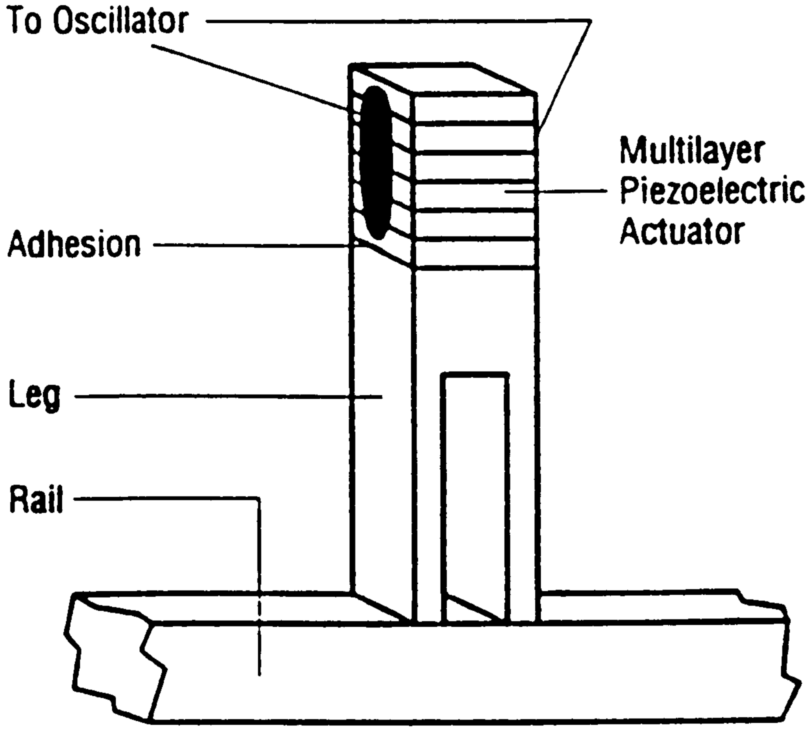


PRINCIPLE OF PROPAGATING WAVE TYPE MOTOR



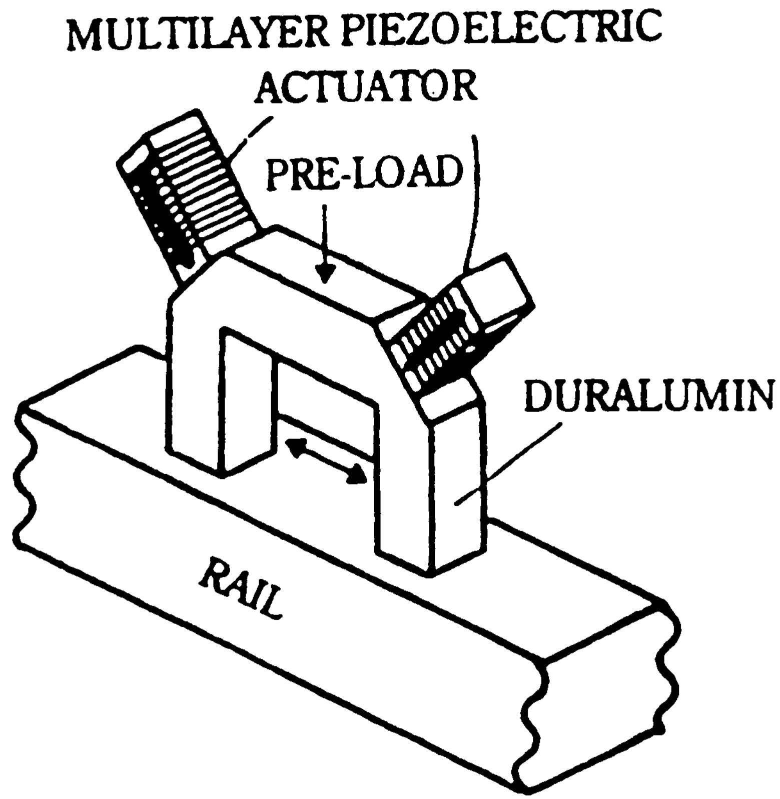
STRUCTURES OF USM'S





Standing Wave - Type

High efficiency
Lack of controllability



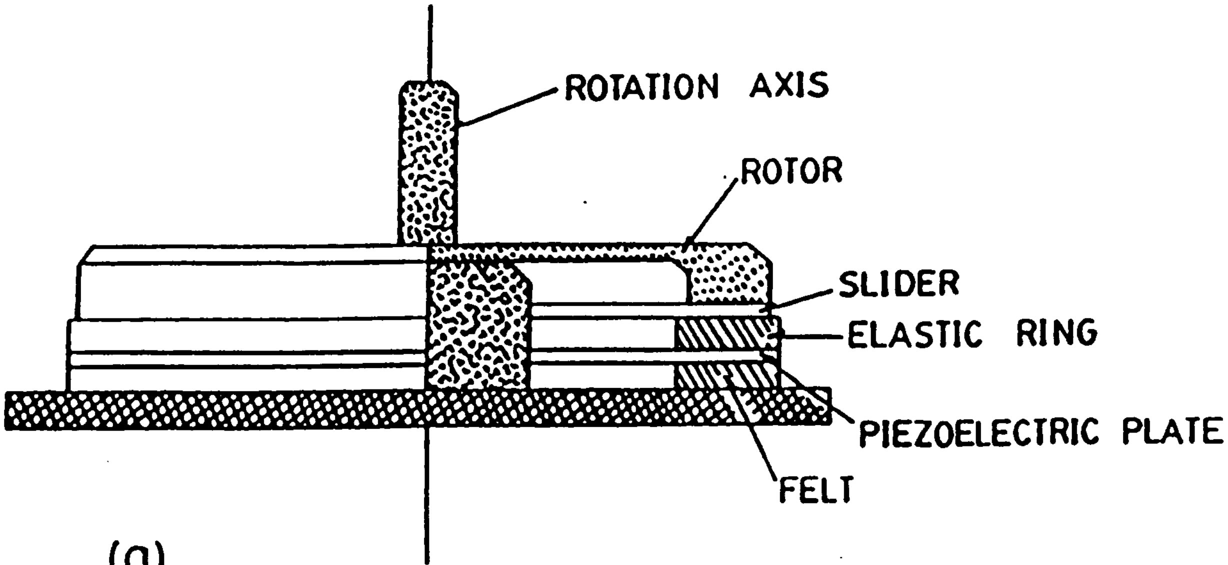
Travelling Wave - Type

Low efficiency
Good controllability

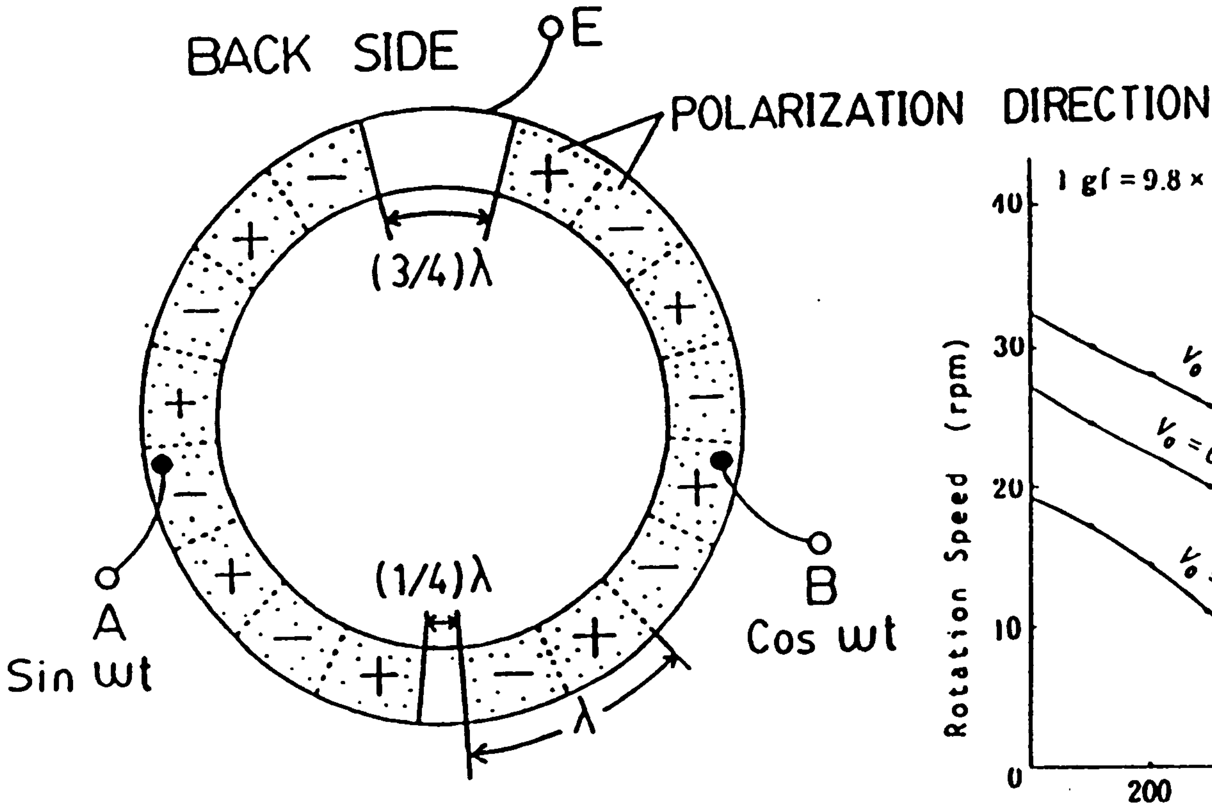
ROTARY-TYPE (Shinsei Kogyo Co.)

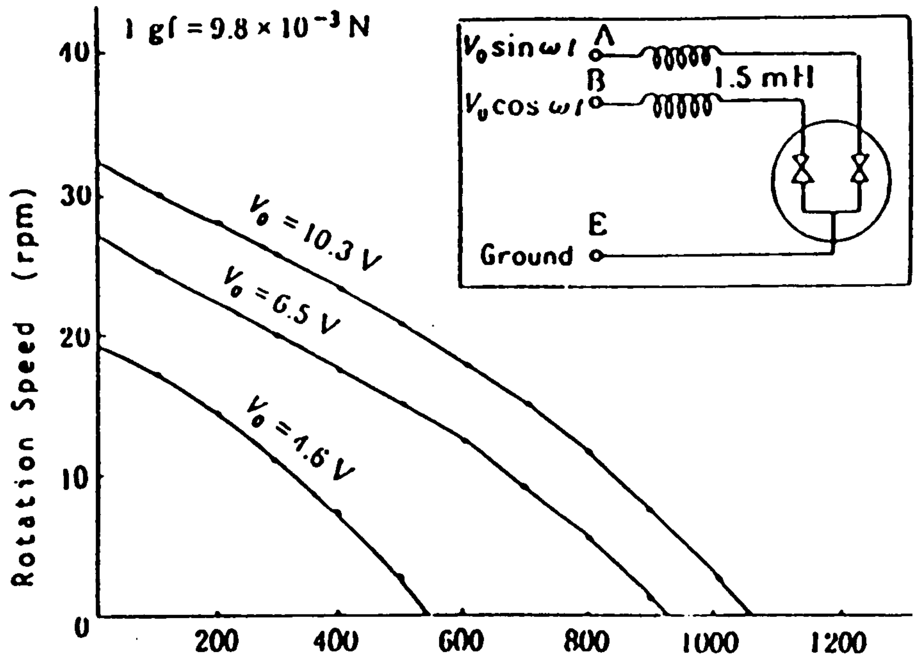
MERITS

1) Efficiency 30 %
2) Torque 1 kg cm
3) Reversible Rotation



(a)





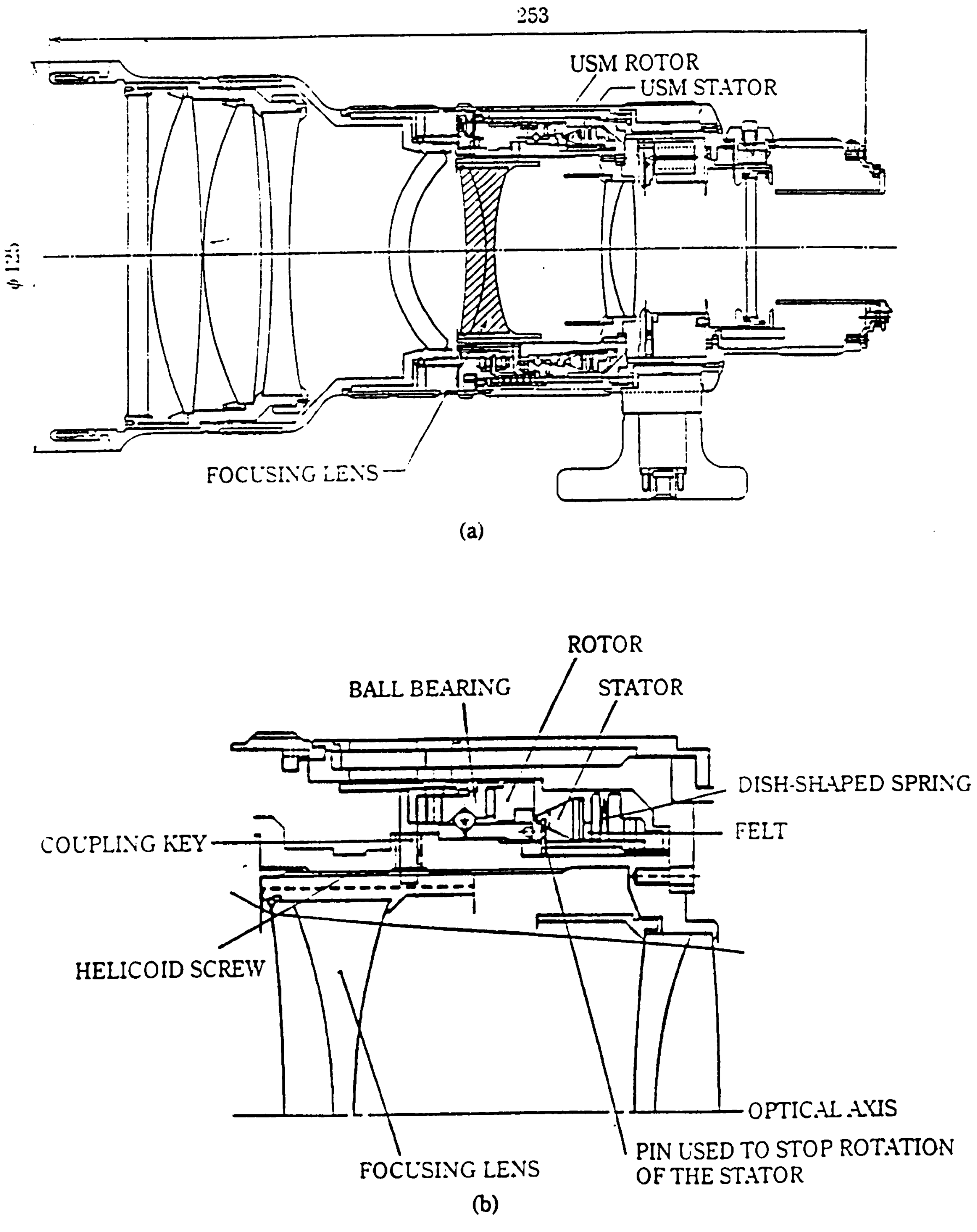


Fig. 6.4. Installation of the ultrasonic motor in a lens (dimensions in mm): (a) cross-section; (b) detail.

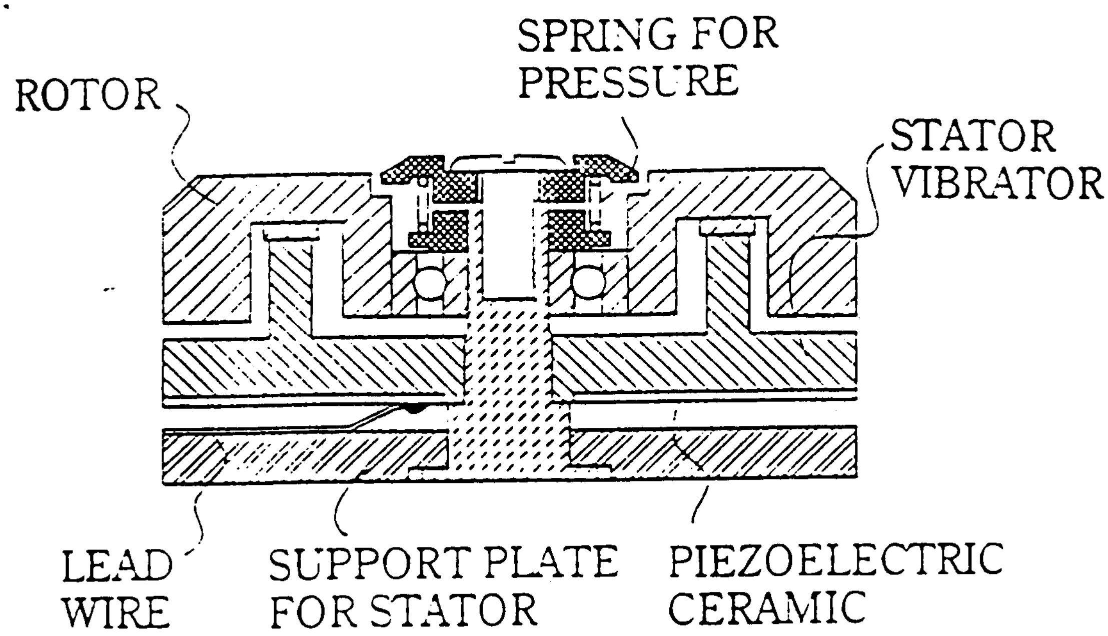


Fig. 6.7. Construction of the motor shown in Fig. 6.6 (stator: B_{03}-mode disk; 2-phase driving).

Table 6.2. Basic specifications of Seiko watch motor

Outside diameter	10 mm
Thickness	4.5 mm
Driving voltage	3 V
No-load speed	6000 rev min^{-1}
Starting torque	0.1 mN m
No-load current	60 mA

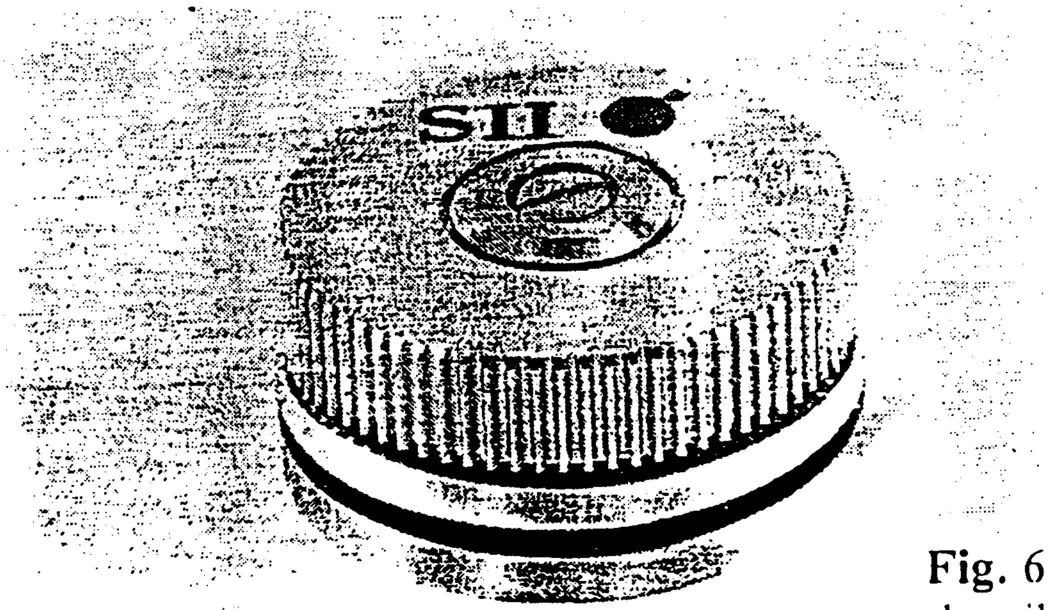


Fig. 6.6. Small motor fc
the silent alarm of watcl
(diameter 10.0 mm),
(Seiko Electric Industria
Co. Ltd).

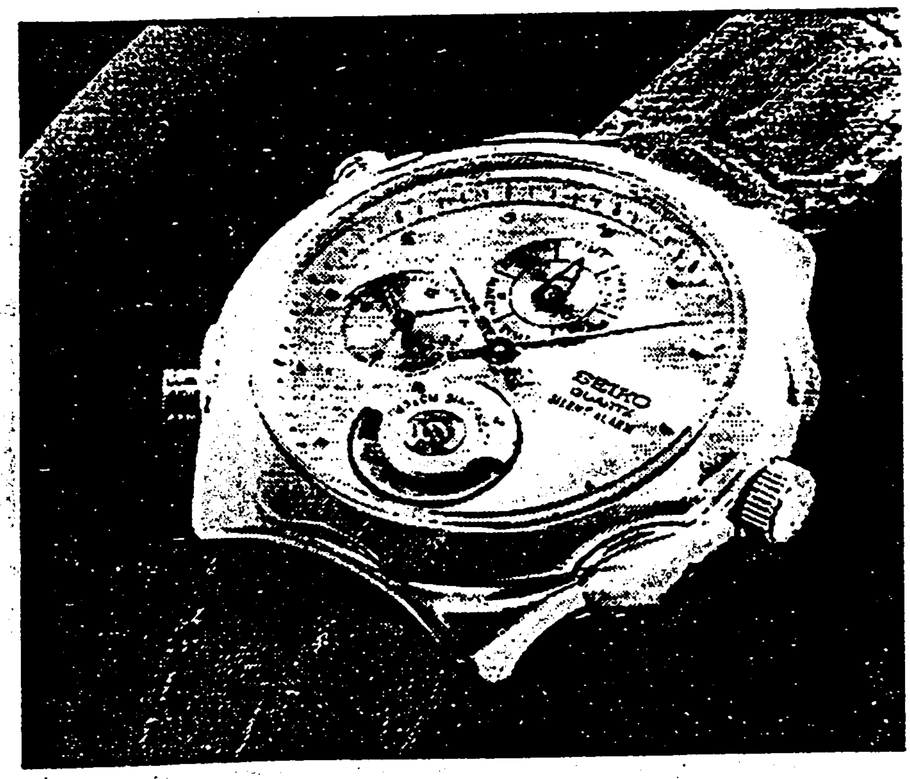
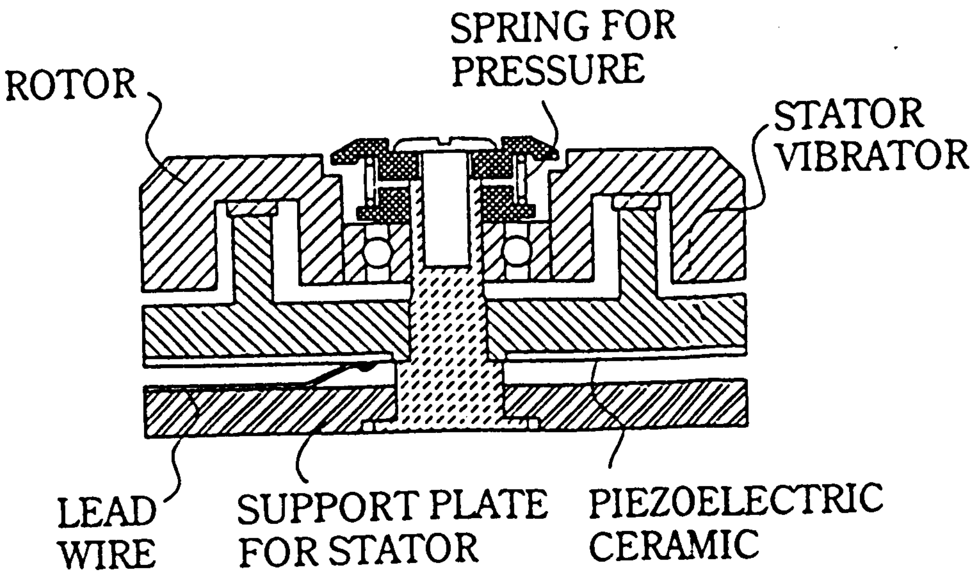
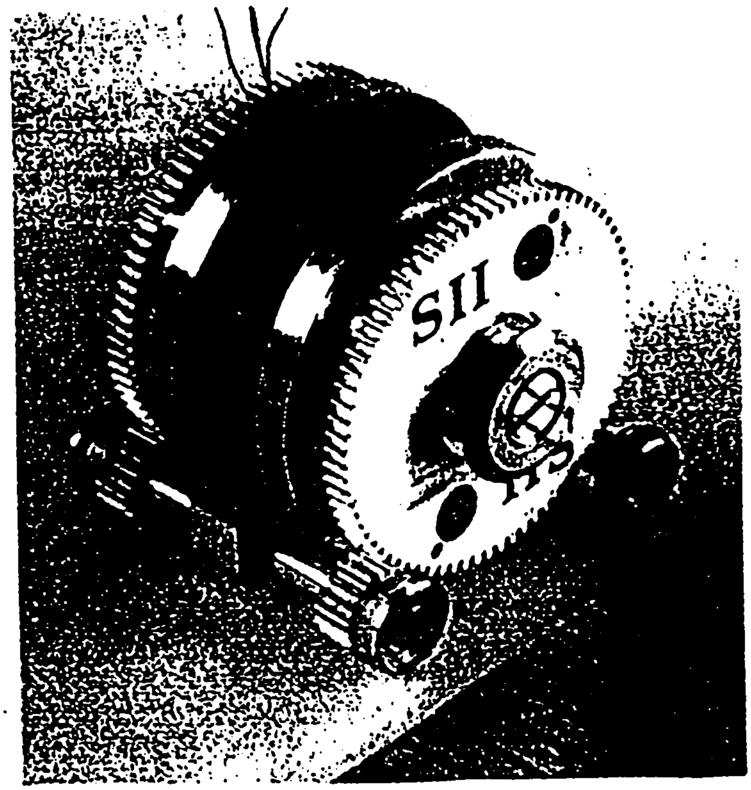


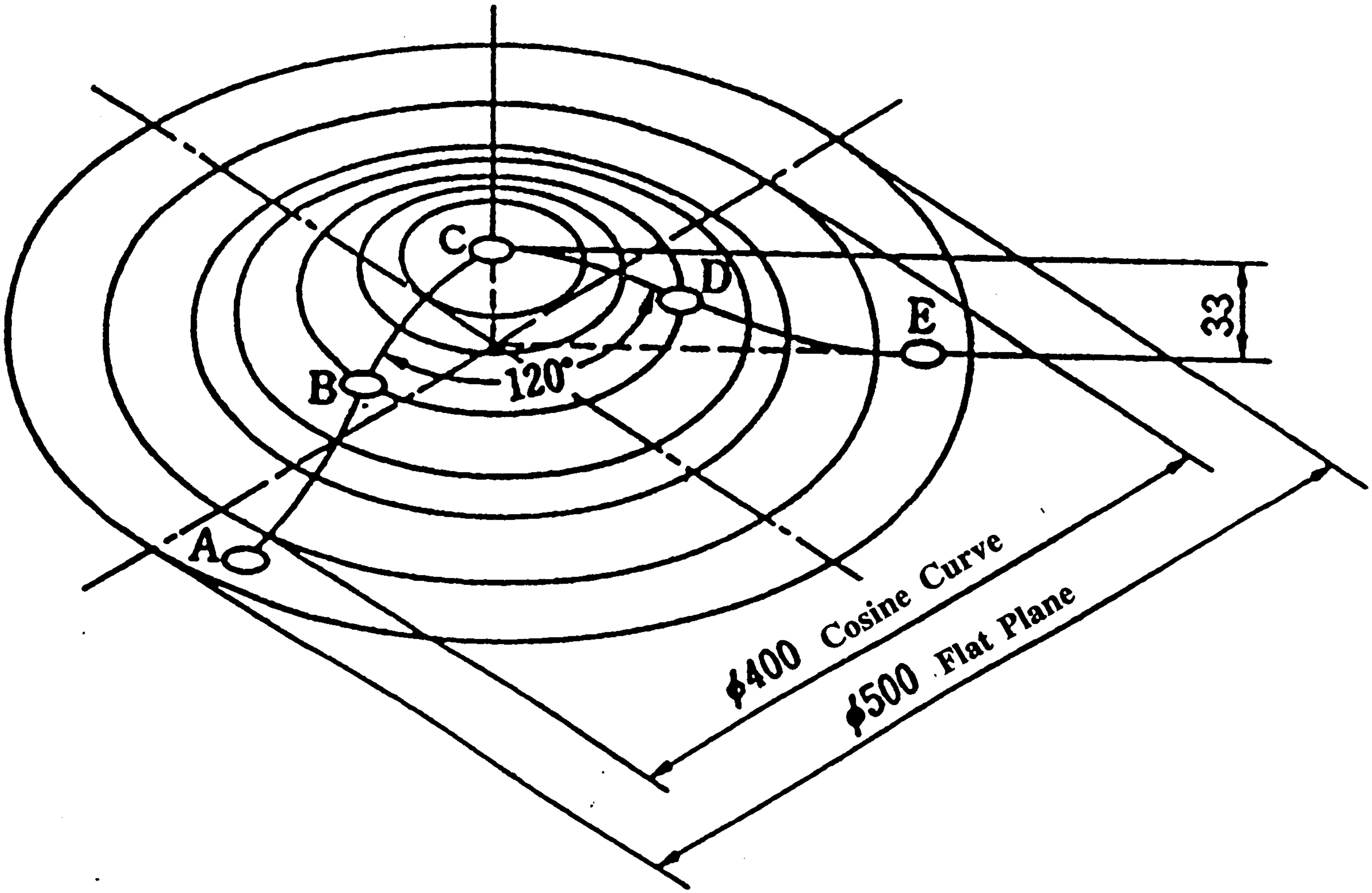
Fig. 6.8. Watch equipped with a silent alarm using an ultrasonic motor (Hattori Seiko Co. Ltd).



Construction of Seiko's Ultrasonic Motor



1st Prize "Yamagoshi Jiro" (2nd Competition)

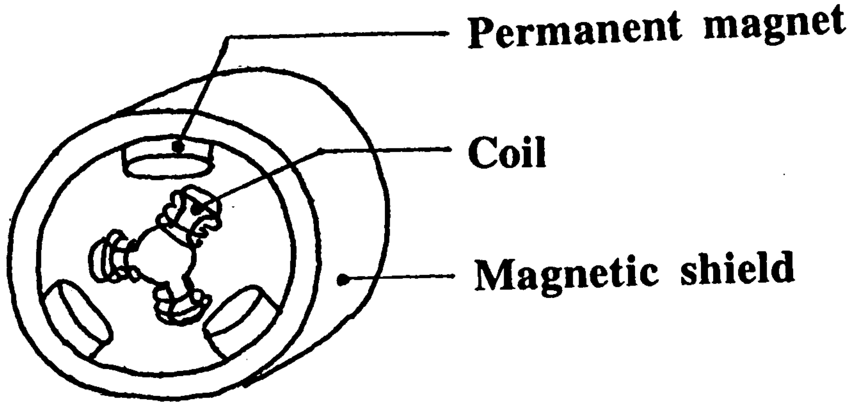


Duralumin Mountain for Micro Machine Climbing

Why Ultrasonic Motors?

Conventional Electromagnetic Motors

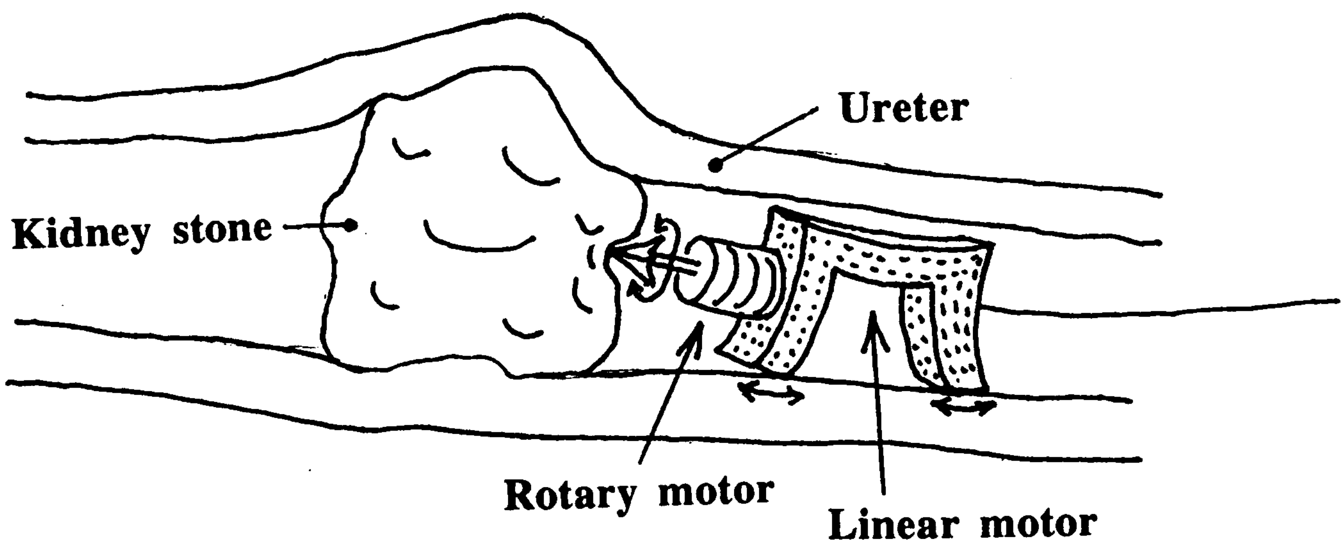
Size limit > 1 cm^3

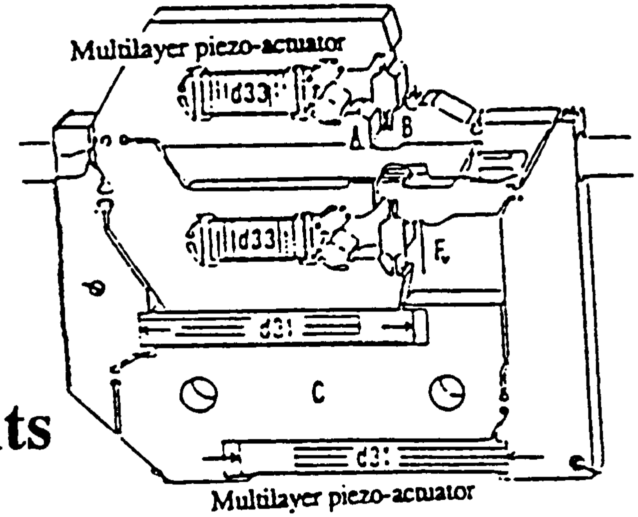


Ultrasonic Motors

Simple structure
Efficiency insensitive to size

$\Big\}$ **Compact size**



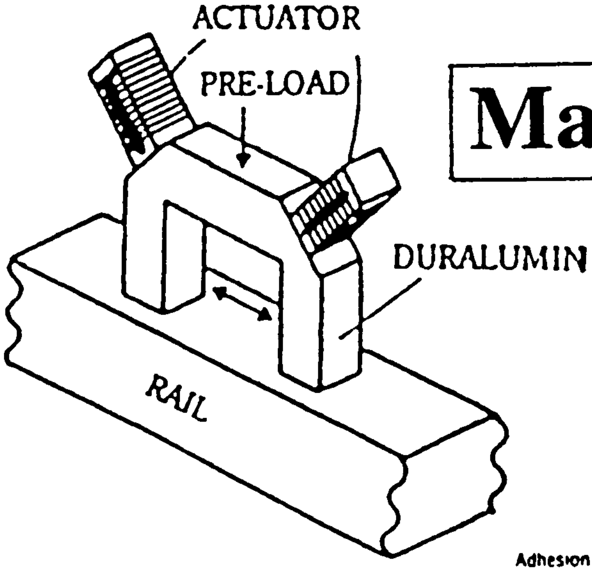


Higher Function

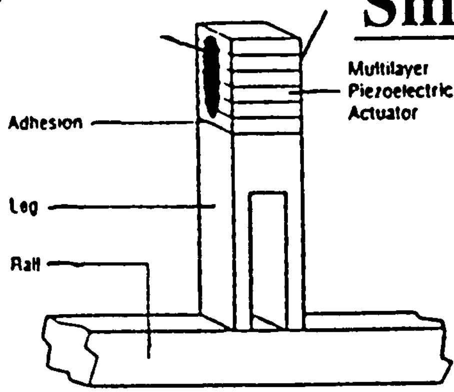
Add Components

Material/System **(Ultrasonic Motor)**

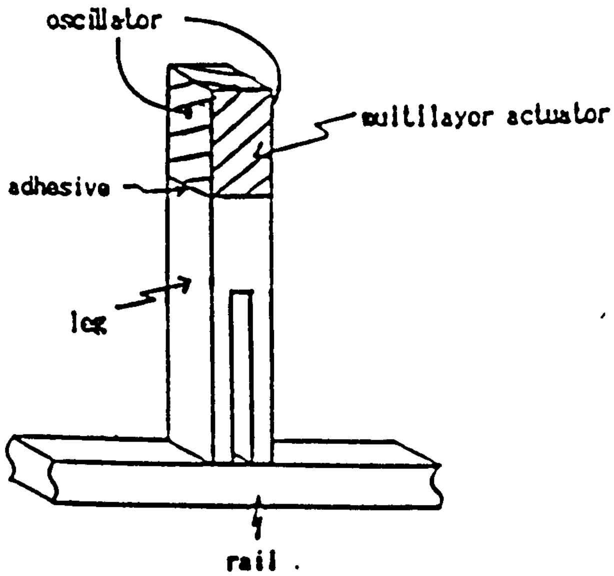
Reduce Components **(Combine sensors & actuators)**

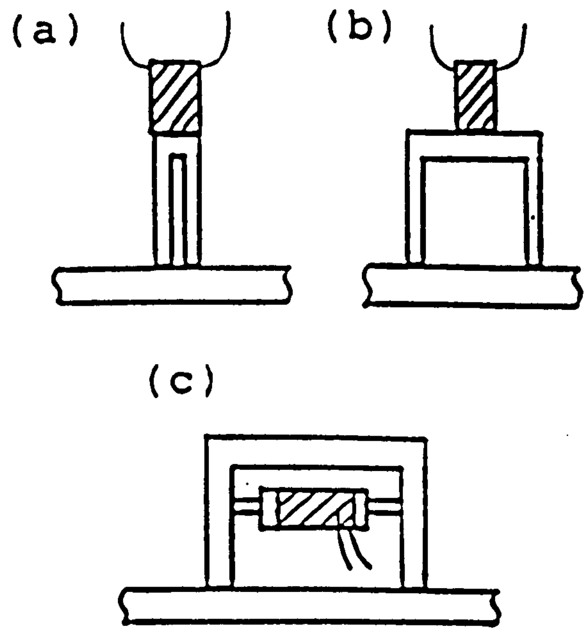


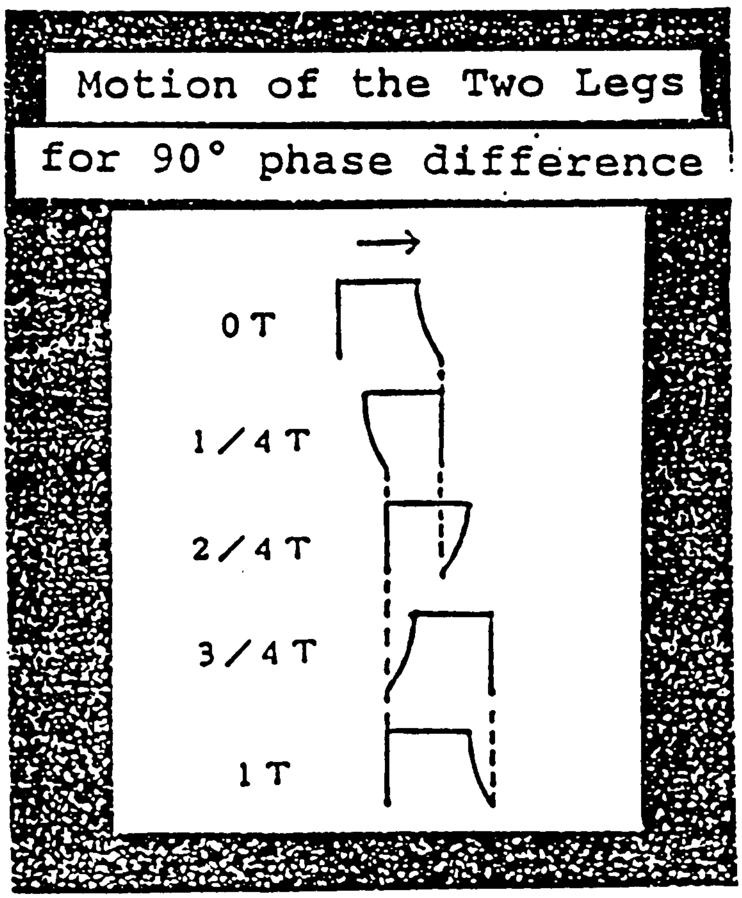
Smaller Size,Lower Cost



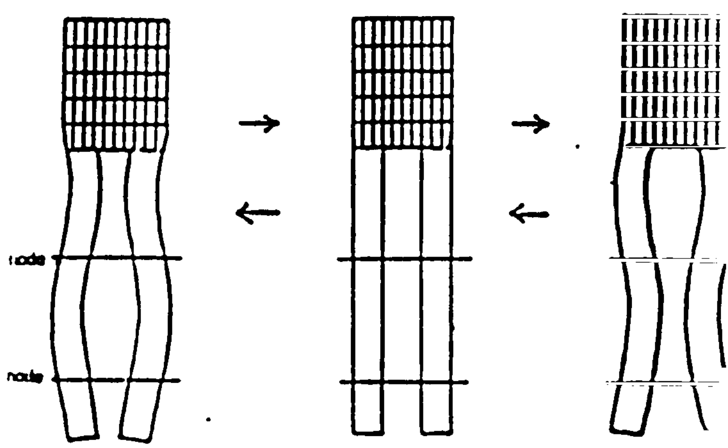
LINEAR-TYPE (Sophia University)

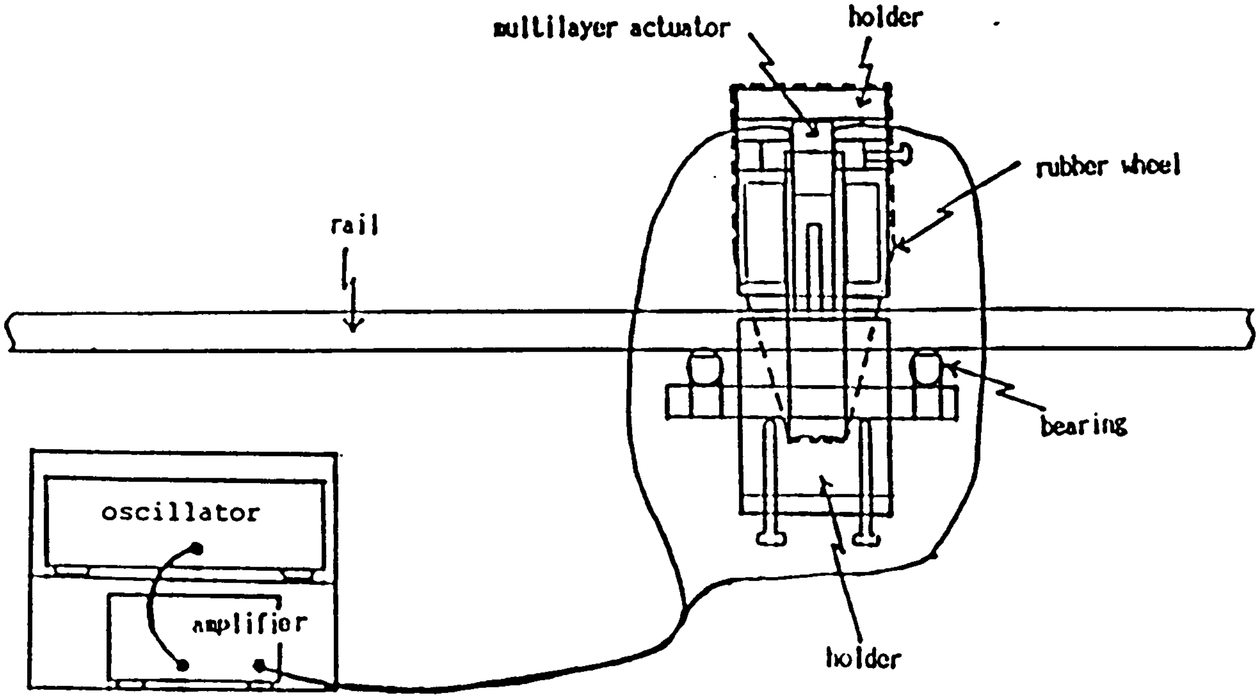


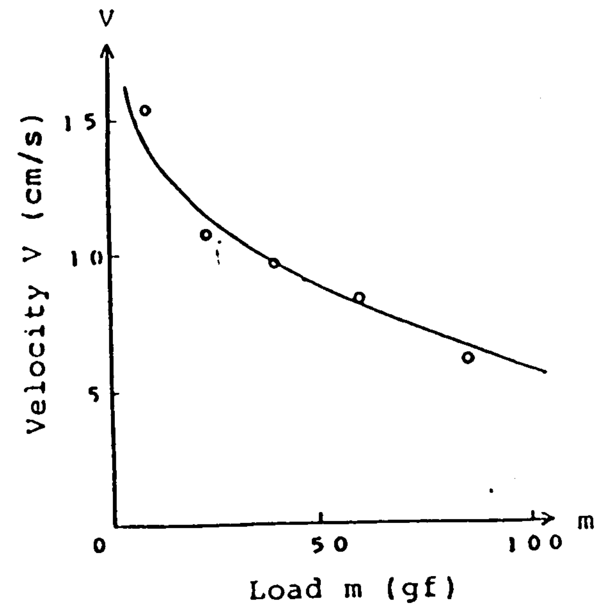


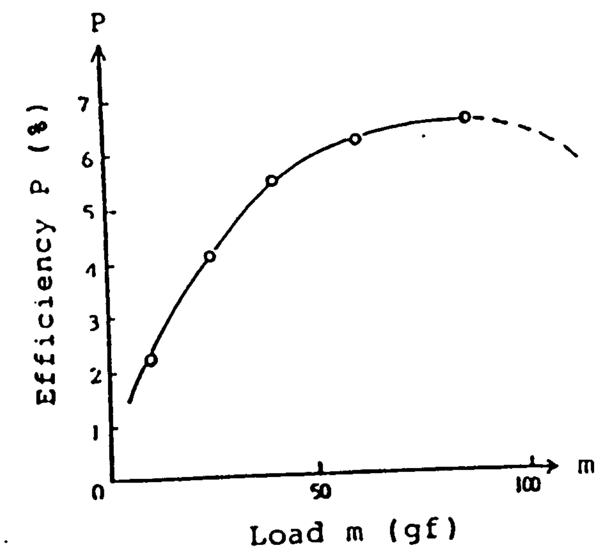


Dynamic Finite Element Meth

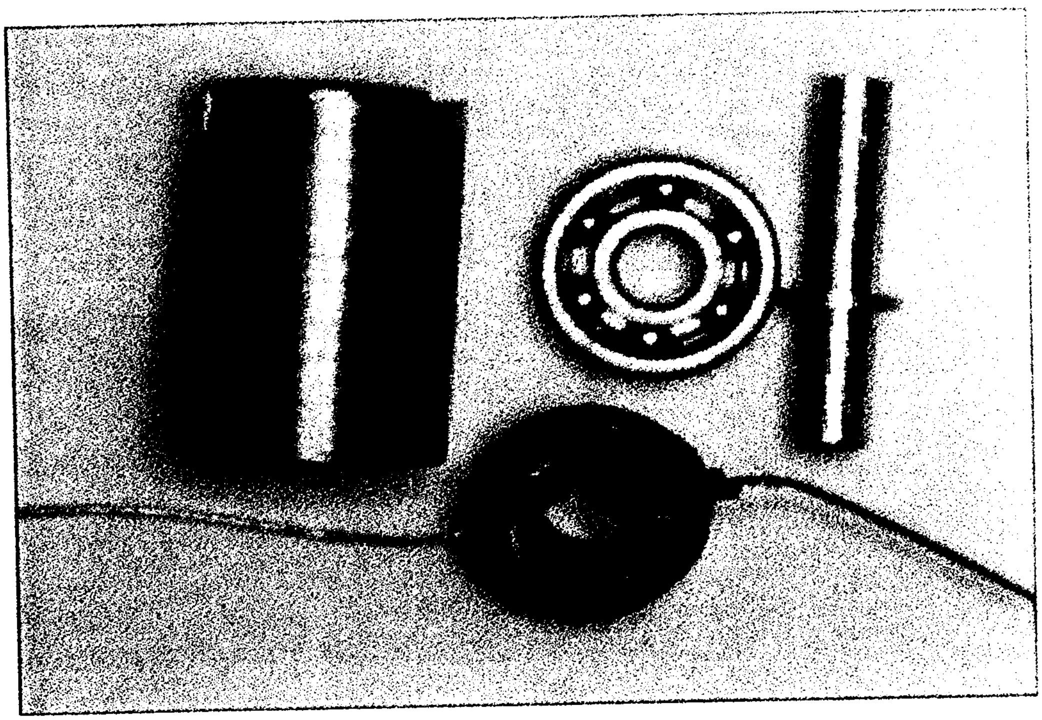






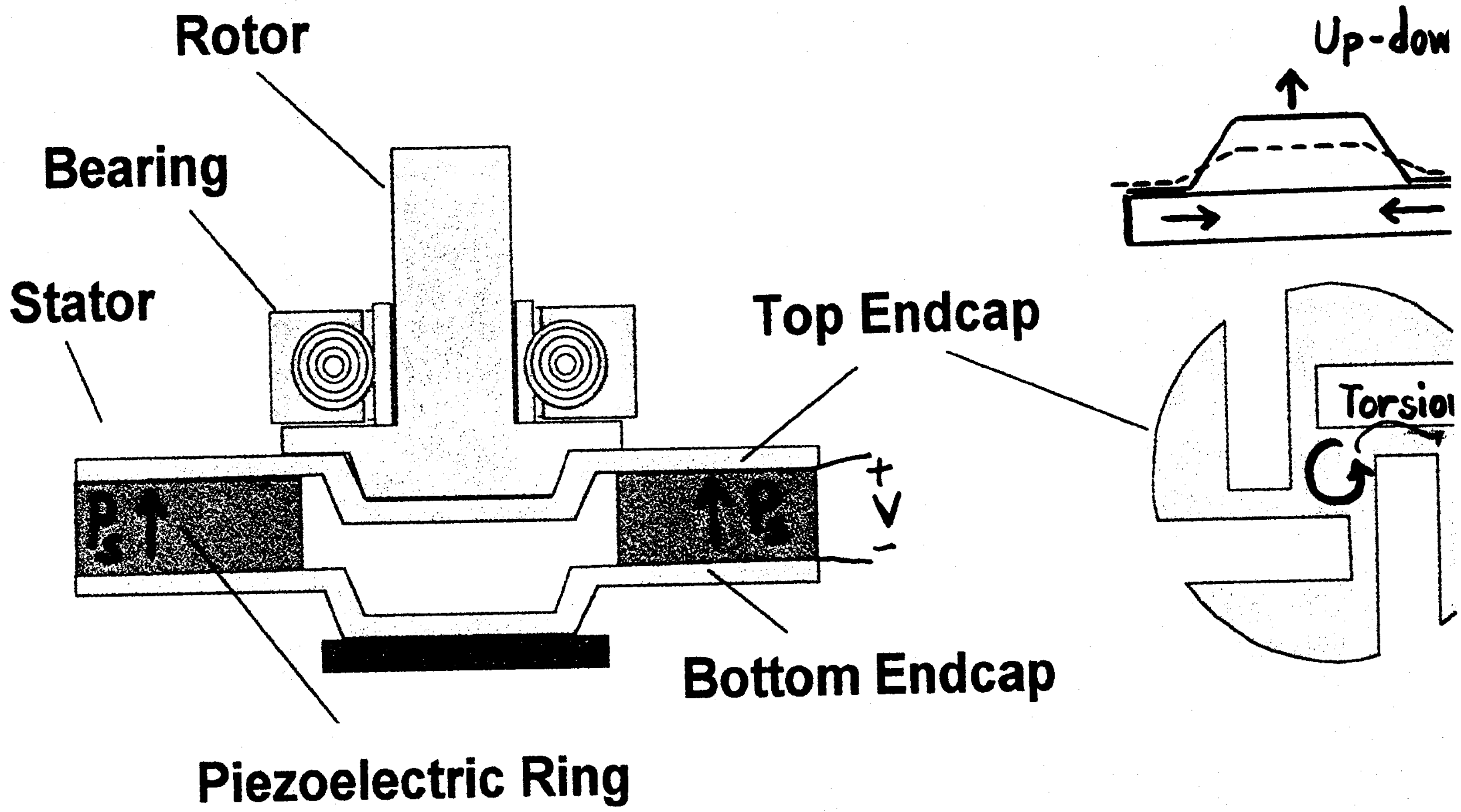


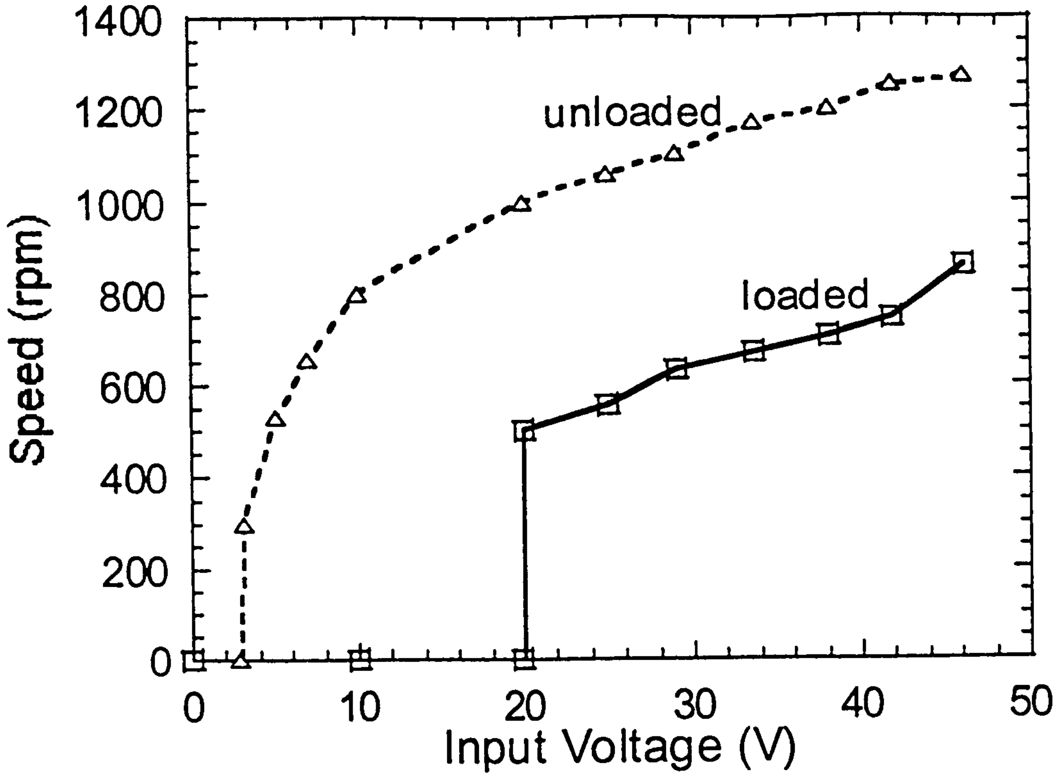
Maximum Speed	20 cm/s
Maximum Load	200 gf
Maximum Efficiency	20 %
Input Power	0.7 W

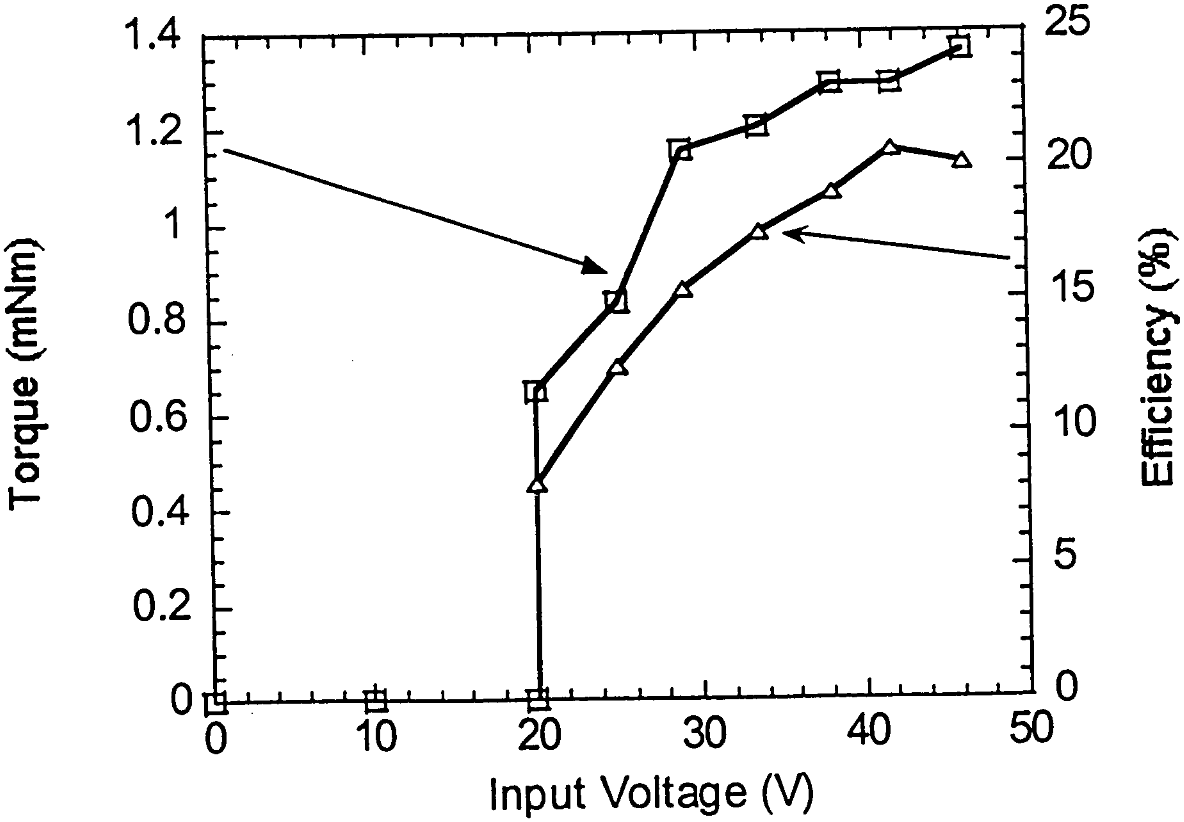


STRUCTURE OF THE DESIGN

"Windmill" Motor







Motor Characteristics of a "Windmill" Type

SUMMARY

	Ultrasonic Motor	Electromagnetic Motor
Speed:	Low	High
Torque:	High	Low
Drive:	Direct	Gear is coupled
Miniaturization:		
	< 3 mmϕ	> 1 cm^3
Overload:	Homeostatic	Self-destructive

FUTURE WORK

(1) USM designs (further miniaturization)
  *standing wave types
  *less number of components
  *simpler manufacturing process
(2) low loss & high vibration velocity piezo-ceramics
  *much "harder" piezoceramics
(3) piezo-component designs with high resistance to fracture and good heat dissipation
(4) high frequency/high power supplies
  *antiresonance mode usage